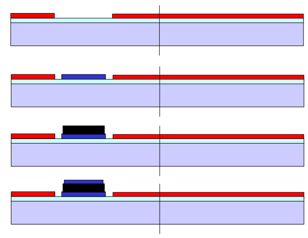
2.008 Design & Manufacturing II

Spring 2004

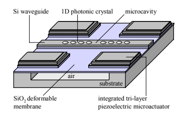
MEMS, Tiny Products

Tunable microcavity waveguide fabrication process flow

front-view *side-view (thru' waveguide)* Si SiO_2 PZT Pt/Ti Cr



1. RIE Si trench
2. Pattern Pt bottom electrode
3. Pattern PZT and anneal
4. Pattern Pt top electrode



C. Wong & S. Kim

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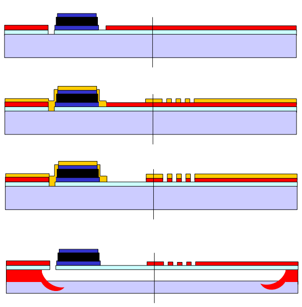


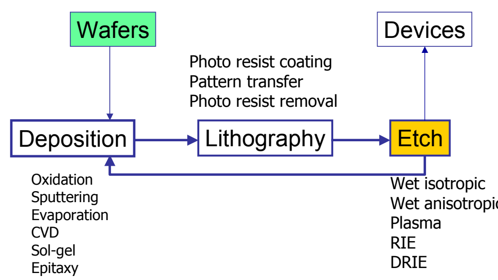
5. RIE SiO_2

6. X-ray lithography of PMMA for Cr mask

7. CF_4 Si waveguide RIE

8. XeF_2 isotropic release etch

Process Flow



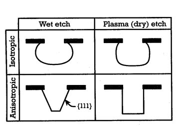
Wet or dry?

Wet

- Low resolution feature size
- Low cost
- Undercut for isotropic
- Wider area needed for anisotropic wafer etch
- Sticking

Dry

- High resolution feature size
- Expensive
- Vertical side wall
- Avoid sticking

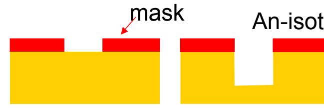


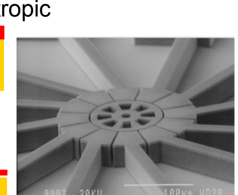
Etching Issues - Anisotropy

-Structural layer
-Sacrificial layer

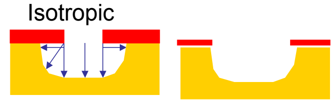
mask

An-isotropic



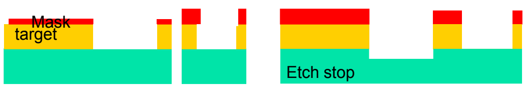


Isotropic



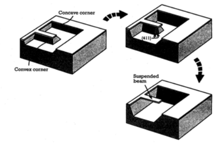
Etching Issues - Selectivity

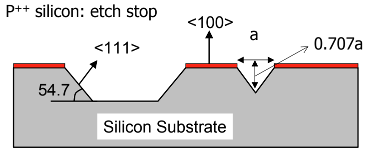
- Selectivity is the ratio of the etch rate of the target material being etched to the etch rate of other materials
- Chemical etches are generally more selective than plasma etches
- Selectivity to masking material and to etch-stop is important



Bulk Micromachining

- KOH etches silicon substrate
  - V-grooves, trenches
  - Concave stop, convex undercut
  - (100) to (111) → 100 to 1 etch rate
- Masks:
  - SiO_2: for short period
  - Si_xN_y: Excellent
  - heavily doped P^{++} silicon: etch stop

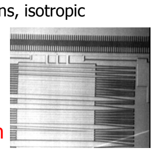




Dry etching

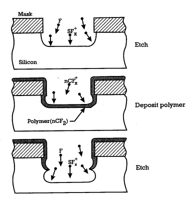
- RIE (reactive ion etching)
  - Chemical & physical etching by RF excited reactive ions
  - Bombardment of accelerated ions, anisotropic
  - SF_6 → Si, CHF_3 → oxide and polymers
  - Anisotropy, selectivity, etch rate, surface roughness by gas concentration, pressure, RF power, temperature control
- Plasma etching
  - Purely chemical etching by reactive ions, isotropic
- Vapor phase etching
  - Use of reactive gases, XeF2
  - No drying needed

stiction

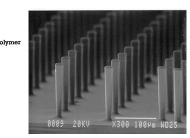


DRIE (Deep RIE)

- Alternating RIE and polymer deposition process for side wall protection and removal
- Etching phase: SF6 /Ar
- Polymerization process: CHF3/Ar forms Teflon-like layer
- Only 9 years after the Bosch process patent, 1994



-1.5 to 4 μm/min
-selectivity to PR 100 to 1

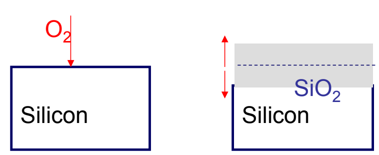


Deposition processes

- Chemical
  - CVD(Chemical Vapor Deposition)
  - Thermal Oxidation
  - Epitaxy
  - Electrodeposition
- Physical
  - PVD
    - Evaporation
    - Sputtering
  - Casting

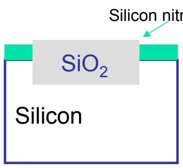
Thermal Oxidation

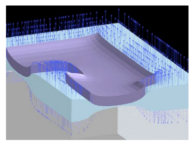
- Silicon is consumed as the silicon dioxide is grown.
- Growth occurs in oxygen and/or steam at 800-1200 C.
- Compressive stress
- ~2um films are maximum practically.
- Simple, easy process for electrical insulation, intentional warpage, etc.



Thermal Oxidation

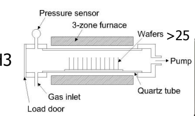
- Oxidation can be masked with silicon nitride, which prevents O_2 diffusion

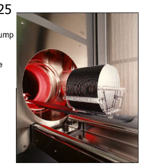




Chemical Vapor Deposition

- Thermal energy to dissociate gases and deposit thin films on surfaces, high productivity, better step coverage
- low pressure (LPCVD), atmospheric pressure (APCVD), plasma enhanced (PECVD), horizontal, vertical
- LPCVD pressures around 300mT (0.05% atmosphere)
- Moderate Temperatures
  - 450°C SiO_2 : PSG, LTO
  - 580-650°C polysilicon
  - 800°C Si_xN_y – SiH4 + NH3
- Very dangerous gases
  - Silane: SiH4
  - Arsine, phosphine, diborane: AsH_3, PH_3, B_2H_6

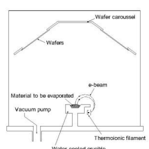




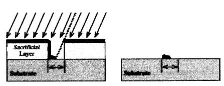
Physical Vapor Deposition

Evaporation

- Evaporated metals in a tungsten crucible
  - Aluminum, gold, Pt, W
- Evaporated metals and dielectrics by electron-beam or resistance heating
- Typically line-of-sight deposition
- Very high-vacuum required to prevent oxidation, load lock



E-beam evaporator

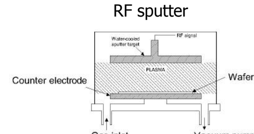


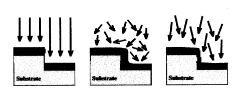
Shadowing

Physical Vapor Deposition – Sputtering

- Sputtered metals and dielectrics
  - Argon ions bombards target
  - Ejected material takes ballistic path to wafers
- Typically line-of-sight from a distributed source
- Requires high vacuum, but low temperature

RF sputter

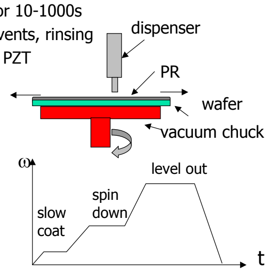




Evaporation vs. Sputtering

Spin Casting

- Viscous liquid is poured on center of wafer
- Wafer spins at 1,000-5,000 RPM for ~30s
- Baked on hotplates 80-500°C for 10-1000s
- Application of etchants and solvents, rinsing
- Deposition of polymers, sol-gel PZT

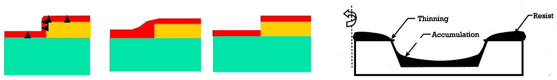


Deposition Issues - Compatibility

- Thermal compatibility
  - Thermal oxidation and LPCVD films
  - Thermal oxidation and LPCVD vs. polymers (melting/burning) and most metals (eutectic formation, diffusion)
- Topographic compatibilitiy
  - Spin-casting over large step heights
  - Deposition over deep trenches-key hole

Deposition Issues - Conformality

- A conformal coating covers all surfaces to a uniform depth
- A non-conformal coating deposits more on top surfaces than bottom and/or side surfaces



Conformal Non-conformal Non-conformal

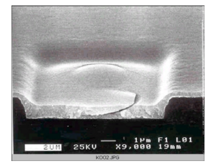


Photo 1 . Cracking of sol-gel deposited PZT after 650C firing

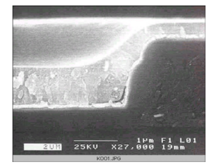


Photo 2. Poor step coverage and high stress evolved at corner of a step

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Lithography (Greek, "stone-writing")

- Pattern Transfer
  - Appication of photosensitive PR
  - Optical exposure to transfer image from mask to PR
  - Remove PR --> binary pattern transfer

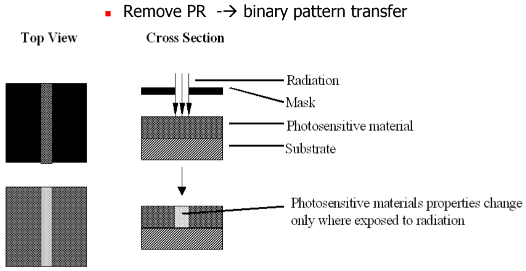
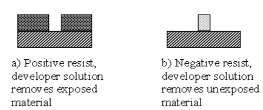
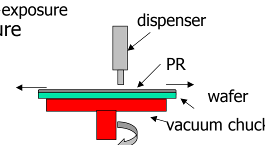


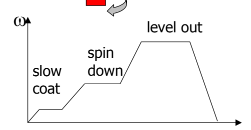
Photo resist

- Spin coat phto-resist
  - 3000 – 6000 rpm, 15-30 sec
  - Viscosity and rpm determine thickness
  - Soft bake ->alignment ->exposure
- Develop PR after exposure
  - Hardbake

Positive Negative





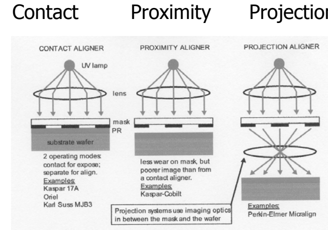


Photomasks

- Master patterns to be transferred
- Types:
  - Photographic emulsion on soda lime glass (cheap)
  - Fe_2O_3 or Cr on soda lime glass
  - Cr on quartz (expensive, for deep UV light source)
- Polarity
  - Light field: mostly clear, opaque feature 2.008
  - Dark field: mostly opaque, clear feature 2.008

Types of Aligner

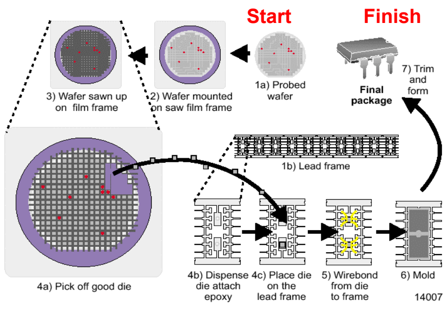
Contact Proximity Projection



Reduction ratio 1:1

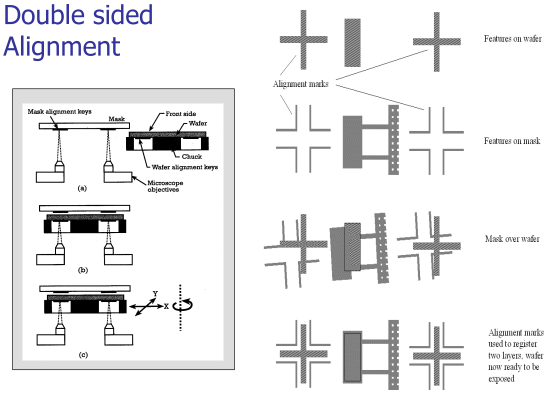
Array of the same pattern → Stepper

IC manufacturing

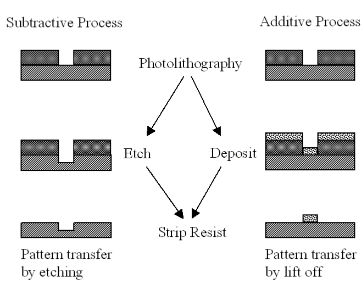


This picture comes from an excellent introductory discussion about IC fabrication at: icknowledge.com

Double sided Alignment

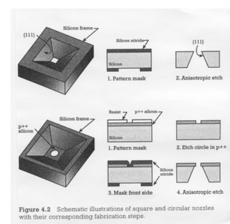


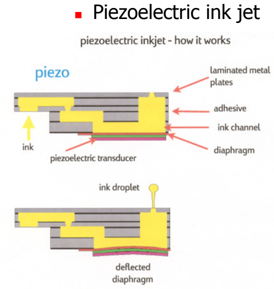
Pattern transfer by lift-off



Bulk machining

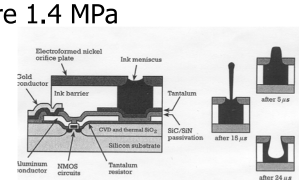
- Square nozzle
- Pumping ink?
  - Piezoelectric ink jet





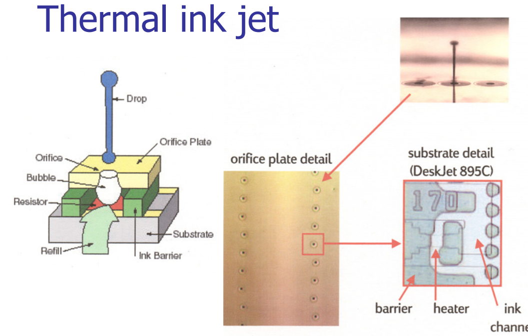
Ink jet printer – A quasi-MEMS case

- Thermal jet by HP
- Superheat ink 250°C
- Peak pressure 1.4 MPa



Refills in 50μs

Thermal ink jet



HP website